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Name of Principal Author and all other author(s) David Jeffcoat:

Principal Author's Organization and address:

AFRL/MNGN
101 W Eglin Blvd, Suite 341
Eglin AFB, FL 32542

Phone:_ (850) 882-2961 Ext. 3362 _____

Fax:___ FAX 850-882-0715 ___

Email:_ david.jeffcoat@eglin.af.mil

Original title on 712 A/B:___**DYNAMIC SENSOR COVERAGE**

Revised title:___N/A_____

Presented in (input and Bold one): (WG15_, CG___, Special Session ___, Poster, Demo, or Tutorial):

This presentation is believed to be:
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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
22 JUN 2005	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Dynamic Sensor Coverage	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **AFRL/MNGN 101 W Eglin Blvd, Suite 341 Eglin AFB, FL 32542**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM201946, Military Operations Research Society Symposium (73rd) Held in West Point, NY on 21-23 June 2005 . , The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**16**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Dynamic Sensor Coverage

David Jeffcoat

Air Force Research Lab

Collaborators

- Mr. Abhishek Tiwari, Caltech
- Dr. Myungsoo Jun, University of FL
- Prof. Richard Murray, Caltech

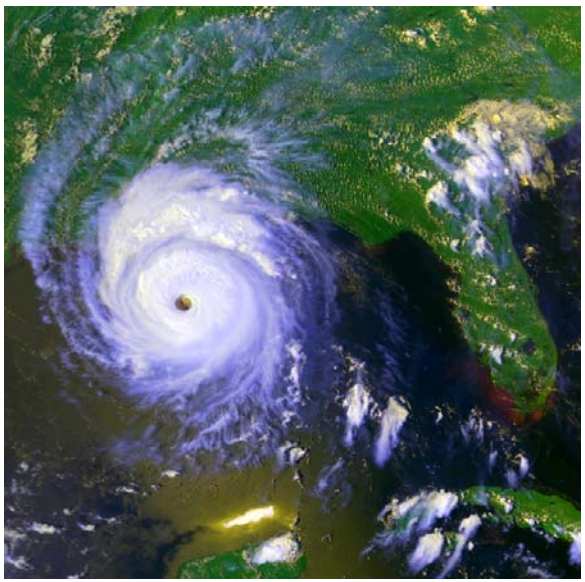
Outline

- Introduction, motivation and applications
- Related previous work
- Problem description
- Results for the single sensor case
- Conclusions and future work

Introduction

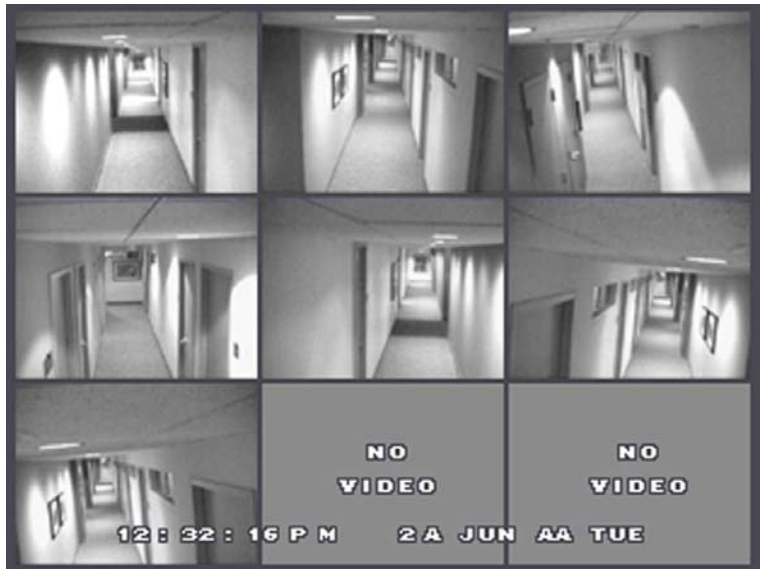
- **Given**:
  - A region with multiple points of interest
  - A “FEW” “limited range” “mobile” sensors
- **Task**: Maintain an appreciable estimate of uncertain parameters at each point in the region

Motivation/Applications



Weather monitoring

Parameters : Temperature, Pressure, Humidity, Wind speed/direction.



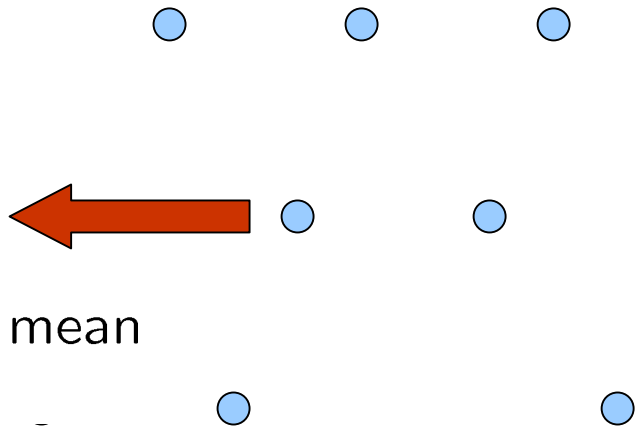
Surveillance

Parameters : Motion

Past Work

- Static coverage techniques based on Voronoi partitions. (Cortes et. al.) ITAC 2004
- Dynamic sensor coverage experiments. (Batalin, Sukhatme). SPIE ’02
- Kalman filtering with intermittent observations. (Sinopoli et. al.) CDC’03
- Markov chains for search and surveillance. (Jeffcoat, Stone).
- Stochastic sensor selection algorithms (Gupta, Chung et. al.) Submitted Automatica Sept’04

Problem Description



N discrete time systems

$$\begin{aligned} x_{i,t+1} &= A_i x_{i,t} + w_{i,t} \\ y_{i,t} &= C_i x_{i,t} + v_{i,t} \end{aligned}$$

w_i, v_i : Gaussian random vectors, zero mean and covariance matrices Q_i and R_i.

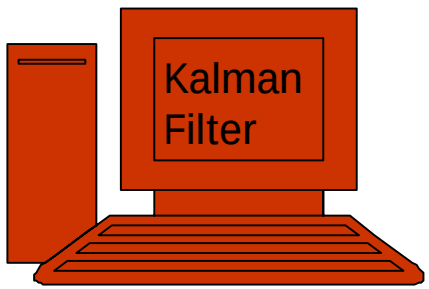
Assumptions

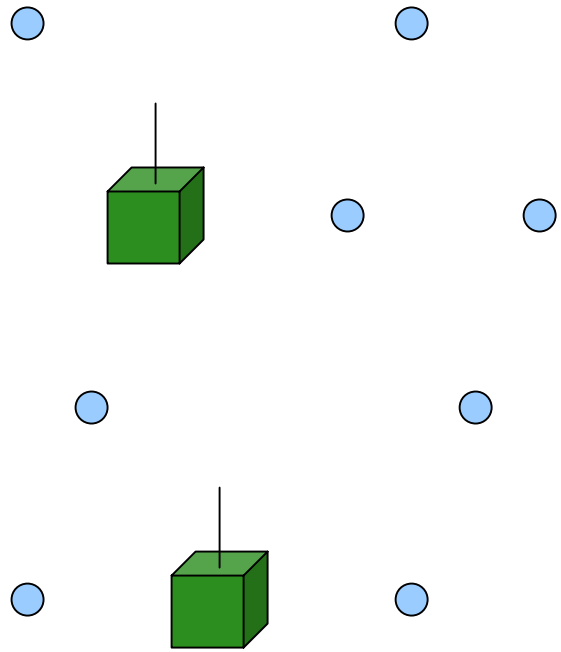
- Systems are decoupled
- Noise processes are independent at different locations

Problem Description

Limited range: A sensor has access to the measurement of system i, if and only if it is currently at system i

Algorithm: Sensors send their measurements to a base station which employs a Kalman filter to estimate the states of all N systems





Sensor at system i ➔ Execute both time and measurement updates.
No sensor at system i ➔ Execute only time update .

Problem Statement

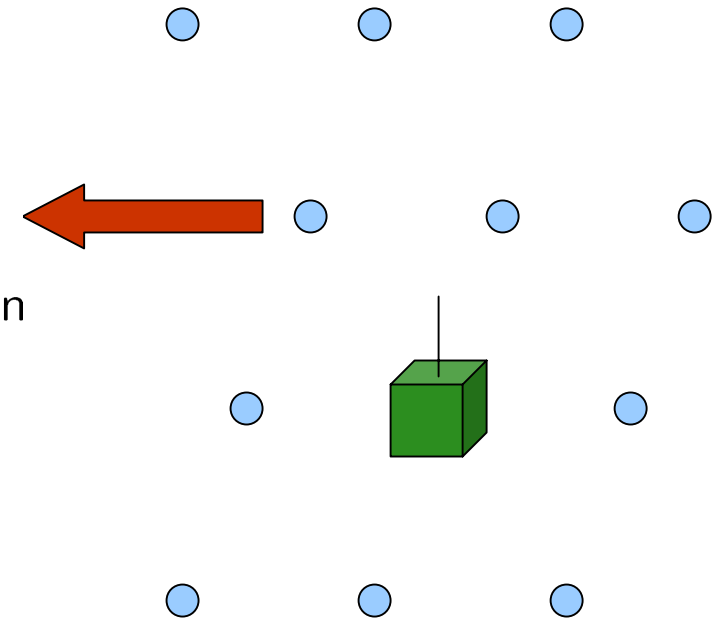
Defn.: We say that the dynamic sensor coverage problem has been successfully solved if for any probability distribution of the sensors π the N limits

$$\lim_{t\to\infty} E[P_{i,t}],\ i \in \{1, 2, \cdots, N\}$$

are finite for any set of initial conditions $P_{i,0} \geq 0$.

If there exists an $i \in \{1, 2, \cdots, N\}$ such that $\lim_{t\to\infty} E[P_{i,t}]$ is unbounded for some $P_{i,0} \geq 0$,then the sensors have failed to solve the dynamic coverage problem.

Single sensor case



N discrete time systems

$$x_{i,t+1} = A_i x_{i,t} + w_{i,t}$$
$$y_{i,t} = C_i x_{i,t} + v_{i,t}$$

w_i, v_i : Gaussian random vectors, zero mean and covariance matrices Q_i and R_i.

Assumptions

- The systems are decoupled.
- The noise processes are independent at different locations.

Failure result

Let $(A_i, Q_i^{\frac{1}{2}})$ be controllable, (A_i, C_i) be detectable and A_i be unstable for all i.

$$\sum_{i=1}^{N} \frac{1}{\alpha_i^2} < N - 1, \tag{1}$$

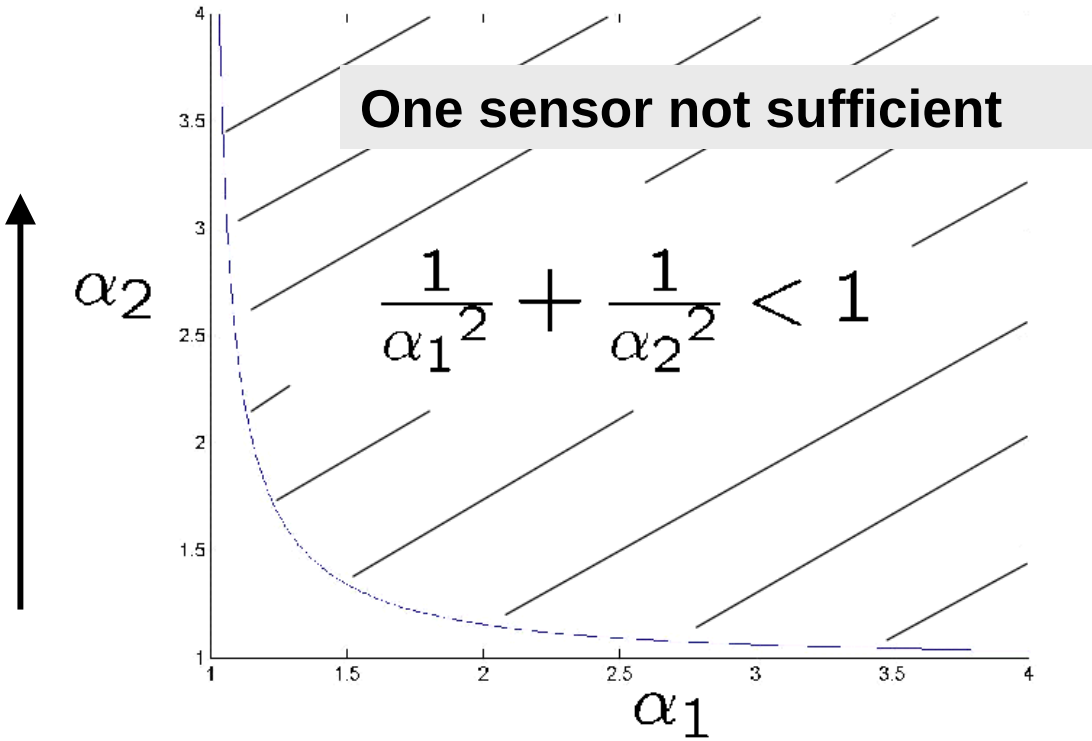
where $\alpha_i = \max_j |\lambda_{i,j}|$, and $\lambda_{i,j}$ are the eigenvalues of A_i, then a single sensor fails to solve the dynamic coverage problem under any random algorithm.

Results for a single sensor

N = 2

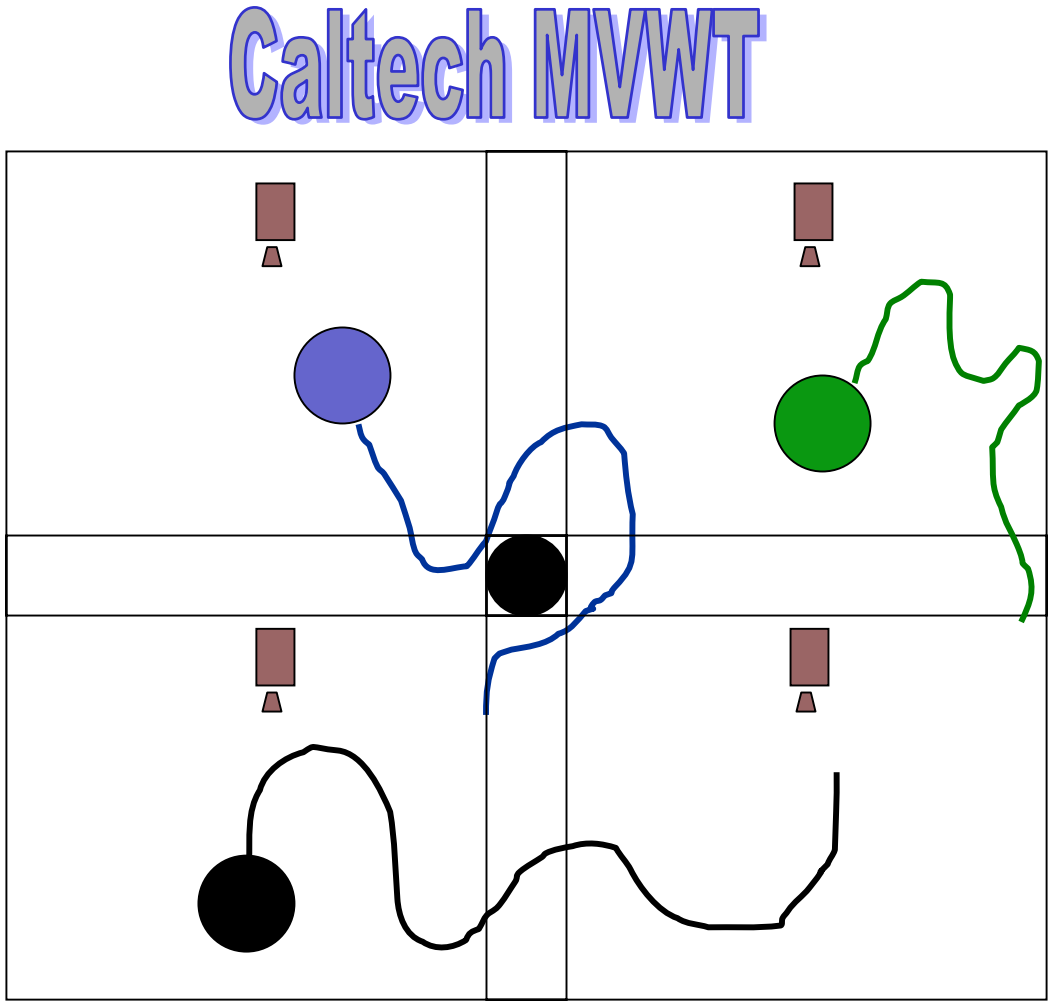
One sensor not sufficient

System Dynamics



http://www.cds.caltech.edu/~atiwari/

Will all this work?



Conclusions

- **What's new? :** A framework for the Dynamic Coverage problem
- **Insightful :** Results are intuitive and provide deeper insight
- **Experiments :** Infrastructure exists
- **Scalability :** The approach can be easily extended to multiple sensors and systems (Dependent case under investigation)

Future Work

- Stability region in the coupled environment case.
- Synthesis of the transition probability matrix for the Markov case.
- Multiple sensor case.
- Convergence to static coverage results as the number of sensors increases.
- Experiments. (Multi Vehicle Wireless Testbed).